Parmeterization of Nonlocal Mixing in the Marine Boundary Layer: A Study Combining Measurements and Large-Eddy

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LONG-TERM GOAL

The long-range goal of this research is to improve understanding of small-scale mixing processes in the atmospheric boundary layer and to incorporate the effects of these processes in mesoscale models. Studies of the atmospheric boundary layer using large-eddy simulation (LES) have demonstrated the value of these models in describing basic turbulent processes in the atmospheric boundary layer. We are now at a point where LES can be applied to a broader range of problems that include decoupled flow in stable boundary layers and cases with strong baroclinic shear coupled with convection. This proposal describes a study to examine the role of turbulent mixing in defining boundary layer structure during conditions with weak winds and stratification and cases with strong vertical momentum flux. LES experiments will be used in combination with measurements taken during the Coupled Boundary Layers Air Sea (CBLAST) field programs to test existing non-local mixing schemes and examine alternatives when these schemes fail. Boundary layer parameterizations developed in this study will provide the connection between surface flux algorithms developed as part of CBLAST, with operational mesoscale models such as the COAMPS forecast model. Our goal is to increase the accuracy of coastal mesoscale prediction by adding physically-based approximations to one-dimensional mixing parameterizations.

OBJECTIVES

Research will focus on two main areas that are poorly represented in boundary layer parameterizations:

- Non-local Momentum transport.
- Stable Boundary Layers.

The main objective of this research is to use LES and observations to improve representations of non-local transport in existing ABL parameterizations. The CBLAST program provides a unique opportunity to combine observations and modeling to better understand the dynamics of transport and mixing in the marine boundary layer. LES modeling has a role in this program by providing a tool for examining small-scale mixing processes that must be parameterized in mesoscale model applications. Numerous recent papers (Brown 1996; Brown and Grant 1997; Derbyshire 1999) use LES to test and interpret ABL parameterizations. These studies point out that there are restrictions on what LES can provide, for example, instability processes must be small enough in scale so that the model can resolve both isotropic turbulence and the anisotropic dynamics of the instability. Mesoscale phenomena such

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14. ABSTRACT
The long-range goal of this research is to improve understanding of small-scale mixing processes in the atmospheric boundary layer and to incorporate the effects of these processes in mesoscale models. Studies of the atmospheric boundary layer using large-eddy simulation (LES) have demonstrated the value of these models in describing basic turbulent processes in the atmospheric boundary layer. We are now at a point where LES can be applied to a broader range of problems that include decoupled flow in stable boundary layers and cases with strong baroclinic shear coupled with convection. This proposal describes a study to examine the role of turbulent mixing in defining boundary layer structure during conditions with weak winds and stratification and cases with strong vertical momentum flux. LES experiments will be used in combination with measurements taken during the Coupled Boundary Layers Air Sea (CBLAST) field programs to test existing non-local mixing schemes and examine alternatives when these schemes fail. Boundary layer parameterizations developed in this study will provide the connection between surface flux algorithms developed as part of CBLAST, with operational mesoscale models such as the COAMPS forecast model. Our goal is to increase the accuracy of coastal mesoscale prediction by adding physically-based approximations to onedimensional mixing parameterizations.

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as sea-breeze circulations are too big for inclusion in LES and may pose significant problems in the assignment of accurate boundary conditions. Nonetheless, by limiting LES experiments to cases of fairly uniform ABL properties a wide range of parameters, such as cooling rates, surface momentum flux, and shear strength, can be explored using LES.

Combining observed boundary layer parameters with LES results will provide the basis for improving existing parameterizations and investigating new approaches for modeling turbulent fluxes in stratified boundary layers. For example, using LES we can determine if turbulent bursts behave as non-local processes that extend through the SBL as suggested by observations, or as more locally driven turbulence phenomena. LES also provides a means for identifying when momentum imparted by swell acts as a source of turbulent energy and if non-local momentum transport is key to this process.

A second priority of this project is the inclusion and testing of non-local mixing parameterizations in a mesoscale model. In many cases, large scale forcing is critical in determining mixing rates for the ABL and must be prescribed to test LES and boundary layer parameterizations. Likewise, testing parameterizations in mesoscale applications is needed to demonstrate improved accuracy. Observations from the CBLAST field programs (primarily the low wind site) will be used to verify if the modified parameterizations improve model forecasts.

To summarize, we plan to address the following science questions:

- What are the turbulent processes that are active in the stable boundary layer over the ocean?
- How does large-scale forcing affect turbulence production in the upper portion of the SBL?
- What effect do swell and wind waves have in controlling the ABL momentum flux?
- Can we account for stable boundary layer processes, such as bursting, through non-local fluxes in ABL parameterizations?

APPROACH

The central hypothesis of the proposed effort is that improvements in existing parameterizations of turbulent processes require a physical basis and that this basis may be gained through analyses of LES results and boundary layer observations. To test this hypothesis, we propose to predict the three-dimensional physical structure of mixing in the marine boundary layer by conducting a series of experiments using an LES model initialized with observed average profiles. These model experiments will focus on four main topics driven in part by the CBLAST field experiments and by needed improvements in boundary layer parameterizations:

- Comparison of the modeled turbulence fluxes with observations from aircraft.
- Comparison of the LES boundary layer structure with the Frech and Mahrt (1995) boundary layer model.
- Analysis of the non-local transports in the LES and formulation of new mixing algorithms for detached boundary layers and baroclinic shear cases.
- Testing of parameterizations in a mesoscale model for time periods overlapping specific CBLAST field study periods.

LES Model

We apply the LES model described in Skyllingstad et al. (1999) and Denbo and Skyllingstad (1996). This model is based on the time dependent three-dimensional Navier Stokes equations with subgrid turbulence closure provided by the filtered structure function (FSF) approach of Ducros et al. (1996). The model horizontal boundaries are periodic, and a radiation condition is imposed at the upper boundary.

Experiments will cover a range of conditions as observed at the low wind CBLAST site. Cases will also be performed for the hurricane and high wind field studies, however, verification of the boundary layer structure in these cases will be more difficult given the observational restrictions. Initial profiles of temperature, winds, and geostrophic pressure gradient will be taken from mesoscale simulations using the COAMPS model to ensure that all forcing fields are adequately prescribed. The focus of the low wind experiments will be on stable boundary layers and situations were wave momentum is being transferred from the wave field to the surface layer. Experiments will be performed using both observed ABL structure (profiles taken from aircraft, nearby radiosonde, or mesoscale model gridded data) and idealized flow conditions.

At the low wind site off of Martha's Vineyard it is anticipated that SBL cases will occur during the field study when relatively warm continental air flows over the colder ocean. For these cases, we will initialize the model as though it is over land and then impose a lower boundary heat flux calculated using the ocean surface temperature and a bulk formulation (this will be modified as the wave boundary layer research efforts devise improved surface flux algorithms). This is equivalent to following a volume of air as it travels from land over a fetch equal to the model run duration divided by the surface wind speed.

If we are reasonably confident in the LES results, then we can use the simulated turbulence datasets to examine features that control the transport of momentum and scalars. For example, non-local terms in parameterizations are designed to account for large eddy transport that covers some portion of the boundary layer depth. Using the LES fields, we can track parcel motions through the flow and directly calculate the functional forms of the non-local transport. A similar exercise can be performed using lidar data, but without knowing the scalar fields or full three-dimensional structure of the turbulent eddies. In cases with decoupled turbulence above the stable surface boundary layer, we can again diagnose the non-local transport produced by episodic mixing events, or bursts, by tracking parcels and calculating the eddy flux variables. Potential parameterization enhancements that will be examined include adding a non-local term for decoupled turbulent layers. For example, one possible approach for parameterizing these cases might use a modified version of the Troen and Mahrt (1985) method. The scheme would first estimate the top of the SBL by searching upward for a Richardson number below a critical value of roughly 1. Following the Troen and Mahrt approach, a bulk Richardson number would be applied to determine the thickness of the decoupled layer, but with a base value taken from the top of the SBL. Profiles for K_f and non-local transport will be set using the standard shape functions, but with scaling provided by the difference between the local wind and the geostrophic wind. Adjustable parameters would be set according to results from the LES cases and observations.

WORK COMPLETED

As planned in the proposal, efforts during the first year were limited in scope because the bulk of the CBLAST effort was concentrated in setting up the low wind field experiment. Efforts will increase in FY 2002 with preliminary model simulations and analysis of data collected during the summer 2001 experiment.

RELATED PROJECTS

This work complements efforts in our core ONR research project comparing COAMPS results with satellite derived wind fields (Samelson and Skyllingstad).

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